# Towards Robust Designs Via Multiple-Objective Optimization Methods

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## ABSTRACT

Fabricating and operating complex systems involves dealing with uncertainty in the relevant variables. In the case of aircraft, flow conditions are subject to change during operation. Efficiency and engine noise may be different from the expected values because of manufacturing tolerances and normal wear and tear. Engine components may have a shorter life than expected because of manufacturing tolerances. In spite of the important effect of operating- and manufacturing-uncertainty on the performance and expected life of the component or system, traditional aerodynamic shape optimization has focused on obtaining the best design given a set of deterministic flow conditions. Clearly it is important to both maintain near-optimal performance levels at off-design operating conditions, and, ensure that performance does not degrade appreciably when the component shape differs from the optimal shape due to manufacturing tolerances and normal wear and tear. These requirements naturally lead to the idea of robust optimal design wherein the concept of robustness to various perturbations is built into the design optimization procedure. The basic ideas involved in robust optimal design will be included in this lecture.

The imposition of the additional requirement of robustness results in a multiple-objective optimization problem requiring appropriate solution procedures. Typically the costs associated with multiple-objective optimization are substantial. Therefore efficient multiple-objective optimization procedures are crucial to the rapid deployment of the principles of robust design in industry. Hence the companion set of lecture notes (*Singl;e- and Multiple-Objective Optimization with Differential Evolution and Neural Networks* ) deals with methodology for solving multiple-objective optimization problems efficiently, reliably and with little user intervention.

Applications of the methodologies presented in the companion lecture to robust design will be included here. The evolutionary method (DE) is first used to solve a relatively difficult problem in extended surface heat transfer wherein optimal fin geometries are obtained for different safe operating base temperatures. The objective of maximizing the safe operating base temperature range is in direct conflict with the objective of maximizing fin heat transfer. This problem is a good example of achieving robustness in the context of changing operating conditions. The evolutionary method is then used to design a turbine airfoil; the two objectives being reduced sensitivity of the pressure distribution to small changes in the airfoil shape and the maximization of the trailing edge wedge angle with the consequent increase in airfoil thickness and strength. This is a relevant example of achieving robustness to manufacturing tolerances and wear and tear in the presence of other objectives.

*All the material in the lecture notes is obtained from the following AIAA papers (which have already been presented and are available in the public domain).*

1. Rai, M. M., "A Rapid Aerodynamic Design Procedure Based on Artificial Neural Networks," AIAA Paper No. 2001-0315, AIAA 39th Aerospace Sciences Meeting, Reno, Nevada, Jan. 8-11, 2001.

2. Rai, M. M., "Three-Dimensional Aerodynamic Design Using Artificial Neural Networks," AIAA Paper No. 2002-0987, AIAA 40th Aerospace Sciences Meeting, Reno, Nevada, Jan. 14-17, 2002.

3. Rai, M. M., "Towards a Hybrid Aerodynamic Design Procedure Based on Neural Networks and Evolutionary Methods," AIAA Paper No. 2002-3143, AIAA 20th Applied Aerodynamics Conference, St. Louis Missouri, June 24-26, 2002.

4. Rai, M. M., "Robust Optimal Aerodynamic Design Using Evolutionary Methods and Neural Networks," AIAA Paper No. 2004-0778, AIAA 42nd Aerospace Sciences Meeting, Reno, Nevada, Jan. 5-8, 2004.

5. Rai, M. M., "Robust Optimal Design With Differential Evolution", AIAA Paper No. 2004-4588, Tenth AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, Albany, New York, August 30th – September 1st, 2004.

The animations that I plan to present during my presentation are from the following AIAA papers (already presented).

1. Rai, M. M., and Madavan, N. K., "Improving the Unsteady Aerodynamic Performance of Transonic Turbines Using Neural Networks," AIAA Paper No. 2000-0169, AIAA 38th Aerospace Sciences Meeting, Reno, Nevada, January 10-13, 2000.

2. Madavan, N. K., Rai, M. M., and Huber F. W., "Redesigning Gas-Generator Turbines for Improved Unsteady Aerodynamic Performance Using Neural Networks," *AIAA Journal of Propulsion and Power*, Vol. 17, No. 3, May-June 2001, pp. 669-677.